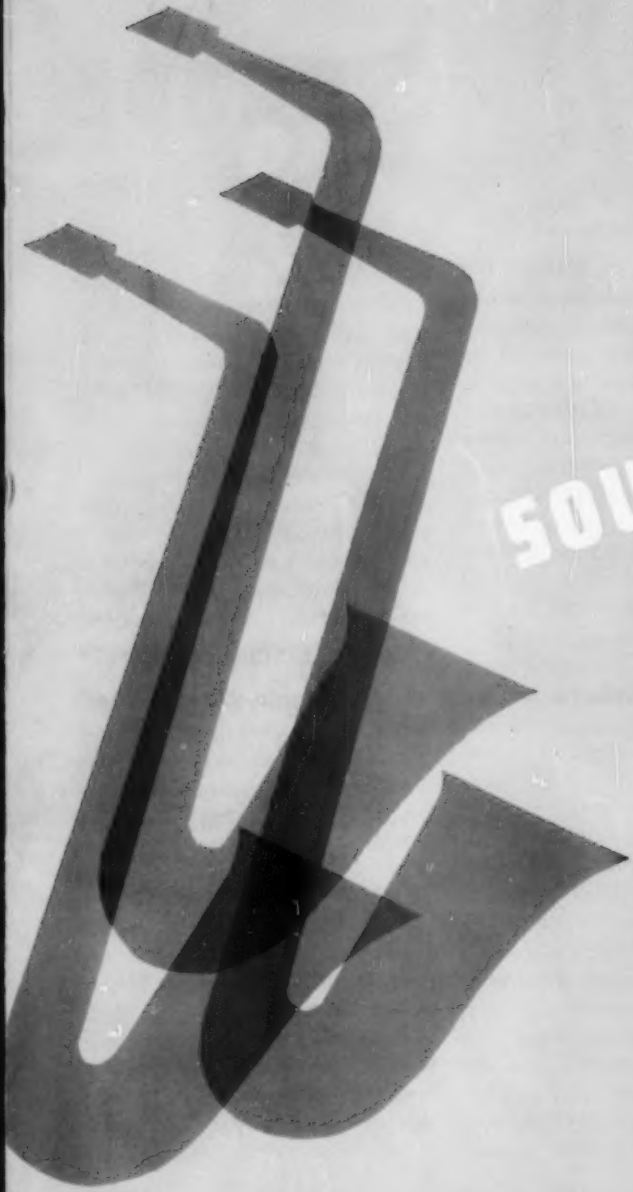

SOUND

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SOUND

VERNE N. ROCKCASTLE

Before you read very far in this Leaflet, close your eyes and listen to the sounds around you. What things can you hear? Do you hear a clock, a car horn, people talking, a dog barking, the wind or rain, or leaves rustling? If it is winter, can you hear the snow falling?

Some sounds are readily heard, even through a closed window. Others you cannot hear, even though your ear is close to them. Sounds differ greatly, both in kind and in loudness. There are many sounds that some animals can hear, but we cannot. We have machines that make some sounds that are much too high for any human to hear, but we can see them on special instruments that analyze sounds and project them as wavy lines on a screen similar to a television screen. Sounds are used to locate objects, to communicate with other people, to produce music, and to interpret mechanical operations (squeaks may mean a machine needs grease). The doctor determines the condition of your heart by interpreting the sound of the thumps in his stethoscope. How many other uses of sound do you know about?

Sound is Vibration

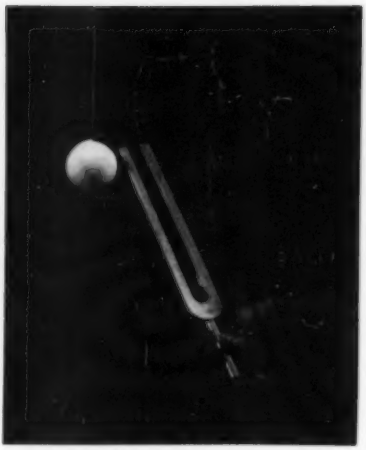
Whenever an object vibrates, it produces a sound. Sometimes the vibration is too fast or too slow for our ears to hear, but often we do hear the vibration. To see that things really do vibrate to produce sounds, turn on your radio and place your fingers on it. If a man is talking, or music is being played do you get a buzzy sensation through your fingers? Do you feel more of a buzz with low sounds or with high sounds?

Go to a piano, place one hand on the top of it and strike a low note. Can you feel the vibration that comes through the wood? Now strike a somewhat higher note. Does the feeling of the vibration change? Try a very high note and see if you can feel the vibration. Some things such as the high notes of a piano vibrate so fast that your fingers cannot feel them very well.

Place a ruler on a table, with most of it projecting beyond the edge of the table. Hold the other part firmly against the table with one hand. Press down slightly on the free end, then let it snap up. Can you see it vibrate? It looks blurred when it moves up and

down. Can you hear a musical sound as it moves? Move the ruler back on the table with less of it projecting, and try again. Does the sound of the note change? Can you still see that the ruler is blurred as it vibrates?

A tuning fork is made to vibrate at a constant rate. Its rate of vibration is determined when the instrument is made at the factory. If you strike a tuning fork against a rubber heel, then hold it near your ear, you can hear its tone. Most tuning forks vibrate so fast, however, that you cannot see them move. Touch the prongs of one to a glass of water after it is struck and you can see how the prongs of the tuning fork spatter the water. They would not spatter water if they were not moving.



Touch a tuning fork to a suspended ping-pong ball and you will see it bounce from the vibration.

Strike a tuning fork and hold one prong against the water surface to see the water spatter.

Hang a ping-pong ball by a thread about a foot long. To do this, glue one end of the thread to the ball, or fasten it with adhesive tape. When the ball hangs motionless, strike a tuning fork and carefully touch the side of one prong to the ping-pong ball. What happens to the ball? This is good evidence that the prongs really vibrate.

Examine the vibrations of various objects and materials around you. Watch the strings of a piano or a violin as the instrument is played. Can you see them move? Feel the throat of a person speaking. Can you feel a vibration from his vocal cords? Put your hand on

the radiator grille of a car while someone toots the horn. What do you feel? Remember that every sound you hear was made by something vibrating.

Pitch

Sometimes objects vibrate at a constant rate when struck. Then they make a steady tone such as a tuning fork, or a piano string. The rate at which these things vibrate is called their *pitch*. Middle C on a piano has a pitch of 256. This means that the string moves back and forth 256 times each second. Anything that vibrates 256 times each second sounds like middle C, whether it is a whistle, a stringed instrument, a glass tumbler struck with a pencil, or a bird singing.

The pitch of the notes that make up the scale from middle C to the C above middle C is as follows:

Middle C = 256
D = 288
E = 320
F = 341.3
G = 384
A = 426.6
B = 480
C = 512

Notice that the octave above middle C has a pitch that is just twice the pitch of middle C. Each time you double the pitch of a note, another octave is reached. What would be the pitch of the second octave above middle C? What would be the pitch of the third octave above middle C? What would be the pitch of the note that is an octave above the E above middle C? You will learn more about octaves and how they are determined as you experiment with strings.

When objects vibrate at many different rates, their pitch is never constant; they make noise. When you clap your hands, you cannot hear a musical note because the vibration rate changes rapidly during the instant of hand-clapping. A clap makes a noise instead of a note. A noise is caused by vibrations that have no pattern to them. They are just a jumble. A note is a vibration that is constant for at least a short time and you are aware of its tone.

What Affects Pitch?

Length. When you plucked the ruler that extended beyond the table top (page 3), you noticed that the pitch was lower as the ruler became longer. When the ruler was shortened, the pitch was higher. This helps to show one important factor in determining the pitch of a vibrating body. The longer it is, the lower the pitch. The shorter it is, the higher the pitch.

Look at a piano whose top is opened so that you can see the strings inside. Inside a grand piano it is easy to see the strings. Notice

how the strings for the low notes are very long, stretching from the front all the way to the back of the instrument. The high notes are very short. The piano itself is even shaped to fit the length of the strings. Notice how a grand piano is longer where the bass strings are, and shorter where the high strings are.

When a violin player wishes to raise the note on a single string, he merely presses down with his finger against the neck of the violin and this makes the string shorter. When his instrument is in tune, all his playing is done by shortening and lengthening the strings as he moves his fingers up and down the neck. Guitars, ukeleles, banjoes, cellos, and all similar stringed instruments work this way. A harpist, like a pianist, uses different strings to change notes, because there is no way of shortening or lengthening harp strings while he plays.

You can make a simple one-stringed instrument to see how shortening and lengthening a string changes its pitch. Get a piece of wood about one foot long, one inch wide, and one-fourth inch thick. In the middle of each end make a saw cut one-fourth inch deep as shown. Two inches from one end, glue a triangular block of hardwood to make a bridge. Get a 14-inch piece of monofilament fishing line, insert each end in a brass paper fastener, coil the next inch or so around the fastener and put the fastener in the saw-cut at the end of the piece of wood. Turn the ends of the fastener over on the under side. Later, frets can be added as shown to make a scale similar to that found on a guitar or a banjo. A paper staple in the top of the bridge will keep the string from cutting down into the bridge. With this simple instrument, a child can learn to pick out a tune and play it fairly well. He also learns to change the length of the string in order to change the pitch.

An air column can vibrate just

A one-stringed guitar made from a stick, a piece of fishline, and two paper fasteners. A staple forms the bridge.

as well as a string. Organs, flutes, clarinets, and other wind instruments depend upon a vibrating column of air to produce their notes. In an organ, columns of various lengths are used just as different strings are used in a piano. When an organist wishes to play a different note, air is sent by a system of valves to another pipe in the organ. The pipes are wooden box-like structures or metal tubes behind the fancy artificial pipes that decorate the loft in some churches.

In instruments such as the clarinet, holes are opened and closed in order to change the length of the air column that is vibrating. Opening a hole has the same effect on an air column as placing a finger on a string. It permits the air column to vibrate as far as that point. If you wish to vibrate the air column for a greater length, you must put your fingers over successive holes to make the vibrating air column longer.

In a trombone, the air column is changed in length as the slide moves in and out. For a low note, the slide is moved out and the air column is longer. High notes must have a short column, so the slide is moved in. Besides that, the player can change the pressure on his lips to make still different tones.

To see for yourself how a change in the length of an air column varies the sound, cut a soda straw as shown. Put the longer end in a

Blowing gently through the horizontal straw, while raising and lowering the one in the water, makes musical notes.

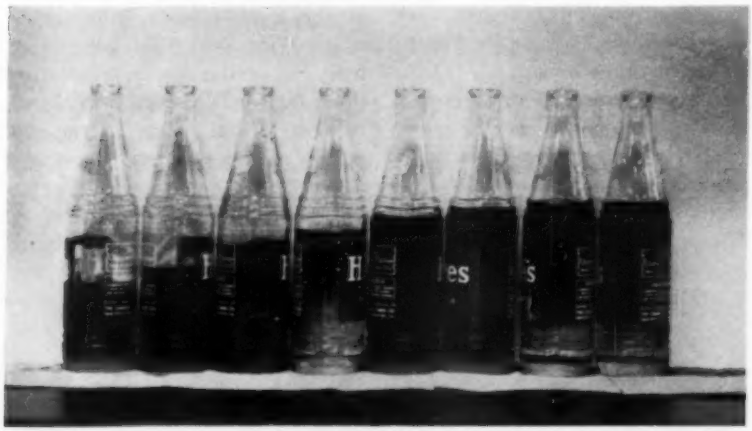
glass of water and blow softly through the shorter end. Can you blow at just the right speed to make a whistle? If not, pinch the end of the blow tube a little where it joins the part that goes down into the water. By manipulating this junction, you will find an arrangement that makes a clear, soft whistle. When you do, raise and lower the glass of water while you blow. Can you hear how the note changes? It is lower in pitch when the water is far down in the tube, and higher in pitch when the level of the water is high in the tube. With some practice, perhaps you can pick out tunes like *Yankee Doodle* on this simple water trombone.

You can also see the effect of

air columns of varying lengths by making a pop-bottle xylophone. Set a series of pop bottles on a table and fill each with enough water to make a musical note in a scale when you blow across the top of the bottle. When you have set up a scale of notes, look at the length of the air column in the bottles. The low note has the longest air column, and the highest note has the shortest air column. Do the rest of the notes show the same relation to the lengths of their air columns?

In a xylophone, wooden blocks of various lengths are used to make notes of a scale. To make a simple xylophone, get some strips of wood about one inch by one-half inch, varying in length from six inches to 18 inches. Arrange them on two tubes of rolled-up newspaper as shown. Tap each with a small wooden mallet and you will see that the shorter ones make the higher notes, and the longer ones make the lower notes. To change the pitch of a block, cut off a little from one end. The more you cut, the higher will be the note of the block. Children can make good xylophones from assorted blocks with a little practice. A coping saw, newspapers (with rubber bands to keep them rolled up), and assorted blocks of wood are all that are needed.

How many other instruments and noise-makers can you find where pitch is determined by the length of something? Stringed instruments, wind instruments, xylophones, organs, calliopes, door chimes, mouthorgans, and many



If you blow across these bottles, the scale rises from left to right. How is the scale arranged if you tap them?

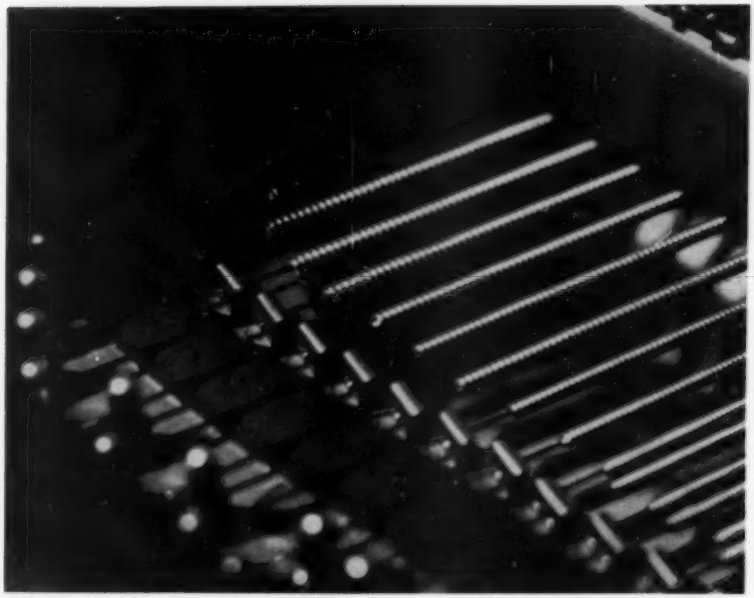
This simple xylophone was made from assorted blocks of wood laid across rolled newspaper. How can you change the pitch of the blocks?

other sound instruments indicate this fact.

Weight. The heavier an object, the harder it is to start and stop its movement. A bowling ball is more difficult to start rolling and to stop rolling than a ping-pong ball. A heavy car needs more gasoline and a more powerful engine to accelerate it, and also more braking action to slow it than does a smaller, lighter car.

In the same manner, it is more difficult to start and stop a heavy vibrating object than it is a light one. If a vibrating object is made heavier, its rate of vibration is slowed, because it is harder to move the heavier object back and forth. This fact is used to control pitch of some vibrating objects.

You can play tunes on a comb if you get one with teeth of varying lengths.



Notice how the base strings of a grand piano are wire-wrapped to lower their pitch.

A low note on a piano comes from a string that is wrapped with a coil of wire to make it heavier. Look into a grand piano, or at a cello or bass violin and notice how the string or strings for the lowest notes are coils of wire instead of simple strings. Inside these coils is a single taut wire. The coil on the outside is only added weight. This makes the string vibrate at a slower rate than it would if no coil were added to it.

Strike a tuning fork against a rubber heel and listen to it. Now wrap one or two rubber bands tightly around each of the prongs. Strike the tuning fork again and listen carefully. Does the pitch change a little? If you are not sure, try this again after reading about beats (page 15), and see if you can hear beats after adding the rubber bands to the prongs. The presence of beats means that the pitch of one tuning fork changed.

On page 8 you read how to make a simple xylophone from blocks of wood of varying lengths. To tune this xylophone, you had to cut a little off the ends of the blocks to raise the pitch. Sometimes, however, too much wood is cut off, making the note too high.

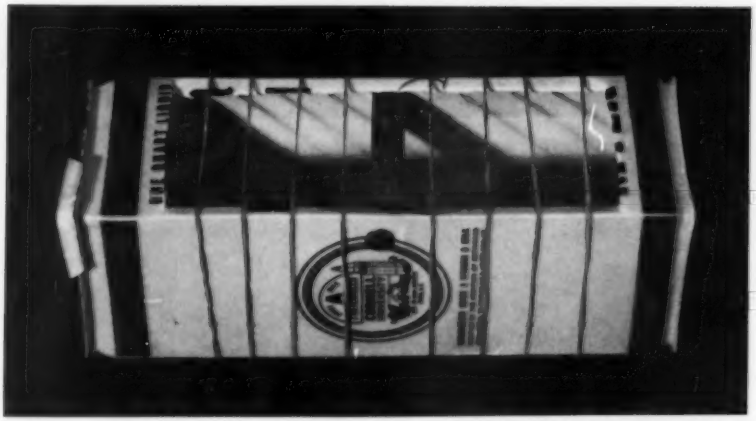
To lower the pitch, some weight must be added. You can do this by pounding a nail into the block, or by adding a screw or two to it. The more weight you add, the lower the note becomes.

Fill a pop bottle or a drinking glass about half full of water. Strike the side of the glass with a spoon or a pencil and listen to the pitch. Now add a little water, strike the glass, and listen again. Does the pitch rise or fall as you add water (weight) to the glass? By adding varying amounts of water to a set of pop bottles or drinking glasses, you can make a scale and play tunes on it. Notice that the scale you make by tapping the glasses has a different arrangement from that made by blowing across the bottles. In the tapping scale, the heaviest bottle is the fullest and has the lowest note. It also has the shortest air column. In the blowing scale, however, the fullest bottle had the shortest air column and the column vibrates to produce the highest note. Bottles arranged for blowing to get the notes are just the opposite of those arranged for tapping to produce the notes.

Sometimes a dense fluid will produce a lower note than a lighter fluid—perhaps because of the greater weight of the fluid that vibrates. When you dissolve salt in water, the pitch of the note will change as the salt dissolves. Fill a quart mayonnaise jar two-thirds full of water and stir it loudly by tapping the sides with the stirring spoon. Add two or three tablespoonfuls of salt to the water as you continue to stir loudly. Notice that when the salt is first added, the pitch of the stirring note drops. Then, as the salt dissolves, the pitch rises again. Does this work with other soluble substances? Does the pitch change when you add some insoluble substance such as sand? By adding different substances to water as you stir, you will discover many interesting but not well understood characteristics of sound.

Tension. A violinist tunes his instrument by tightening or loosening the strings in order to bring them to the desired pitch. To play his instrument, he changes the length of the string by moving his finger along the neck of the instrument, but for tuning the instrument, he changes the *tension* on the strings. Changing the tension or pull on a string changes its pitch just as weight or length changes it.

A simple rubber band-jo will help you see how tension can be used to tune an instrument. To make a simple rubber band-jo, cut a rectangle from one side of a cardboard milk carton as shown, leaving a quarter-inch margin for rigidity along either side. Thumbtack a wooden stick across the opening to brace the sides. Bend down the quarter-inch margins slightly—about 30 degrees. Now



Tightening or loosening the rubber bands tunes this simple "rubber band-jo".

put eight rubber bands around the carton, placing them so they are equally spaced. By pulling down on the sides of the rubber bands you can tighten the section across the opening and make the note higher. Pull up on the sides of the rubber bands to loosen the section across the opening and make the note lower. When all eight strings are tuned, you can play tunes on this simple instrument.

If you cannot get an octave by using eight similar rubber bands, use thicker ones for the lower notes, and thinner ones for the higher notes. Two instruments that have eight notes tuned the same can be used to play a duet.

Sounds Are Waves

Everything you can see around you is made up of tiny particles called molecules. The molecules of wood, steel, the gases of the air, the paper on which this is printed, and even the chemicals that make up your own body have still smaller parts, but it is the movement of the molecules on which sound depends.

To see how the molecules make sound travel, suspend a long coiled spring such as a "slinky" between two chairs or posts. When the spring is motionless, carefully press two of the coils together, hold them until all movement of the spring stops, then release them. Watch the movement that seems to travel back and forth along the spring. It is similar to a sound wave that travels along in the air molecules.

When the coils were released, each compressed the coil next to it. This in turn compressed the coil next to it, and that compressed

A slinky plucked at one end shows very well how sound waves travel.

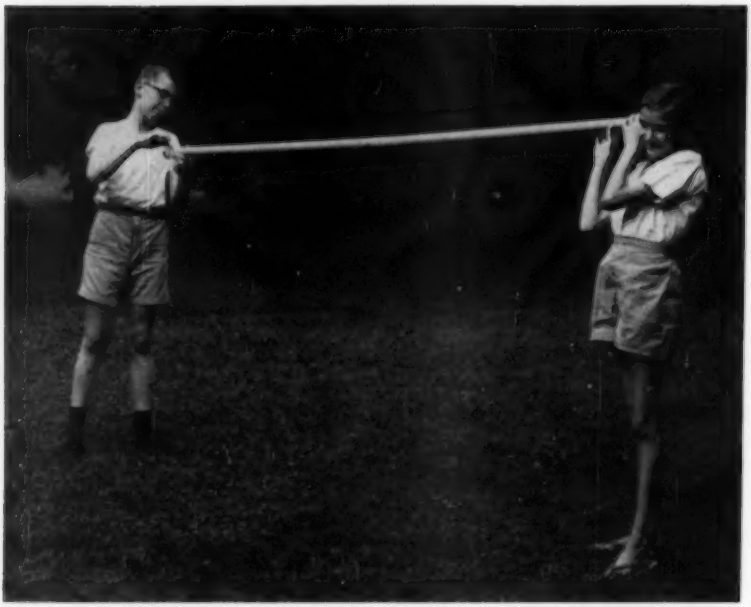
the next coil, and so on. . . . to the end of the spring. There, the last coil pressed against the chair, the post or whatever held it, bounced back, and reversed the compression of coil against coil to the other end of the spring.

In the air, sound is caused when an object quickly pushes some air molecules together for an instant. These molecules press against those that surround them, and they in turn press against still others surrounding them, and so on. Sound waves in air travel outward in spherical shells of energy. The molecules that are being pressed together do not really move very far. No coil of the spring moved very far. Instead, a closeness of the molecules (like the "closeness" of the coils) travels along as each molecule moves towards it neighbor, then away, and its neighbor moves toward its own neighbor, then back.

When you drop a stone into a quiet body of water, ripples move out across the surface. Put a tiny bit of wood or a cork on the surface of the water in a tub, or a large pan. Drop a pebble or a marble into the pan and see if the wood or cork moves along with the ripple. It may move up and down a little as the ripple passes underneath it, and it may move ever so slightly in the direction of the ripple, but mostly it goes nowhere. Only the ripple moves.

Sound waves are ripples in the air. Instead of moving out in a circle from the source of the sound, they move out like invisible balloons being blown up, one after the other, each balloon continuing to expand without ever being broken.

The waves from a tuning fork move out in all directions as alternating compressions (molecules close together) and rarefactions (molecules far apart).



Diane can hear Lee's watch ticking through the tube, even though the watch is eight feet away.

Get a round balloon and blow it up. As you blow, notice what happens to the thickness of the rubber in the balloon. It is thickest when the balloon is smallest. As the balloon gets bigger and bigger, the rubber gets thinner and thinner. If the balloon never broke, but kept on getting larger, how thin would the rubber get?

Sound waves are like balloons that have walls of energy instead of rubber. As the energy balloon gets bigger and bigger, its walls get thinner and thinner. If you are close to the source of the sound, it makes a loud sound when it strikes your ear. If you are farther away, the energy is thinner when it gets to you, and the sound is fainter. If you are very far away, the energy may be so thin that your ear cannot sense it, and you do not hear the sound.

Listen to a watch ticking nearby. Can you hear it distinctly? Now move the watch about five feet away from you. Can you still hear it? If you can, move it another five feet away. How far away can you get and still hear it?

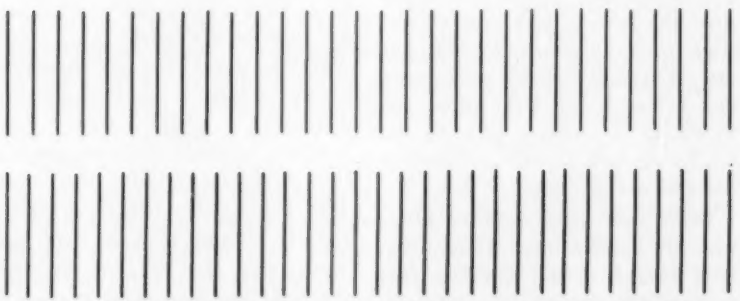
Now get a long cardboard mail-

ing tube. Hold a watch at that distance from your ear. Now put one end of the mailing tube to your ear, and hold the watch in the opening at the other end. Is the tick louder? Inside the tube the energy of the tick does not make spherical shells. Instead, it is kept together as it travels down the tube. It is much easier to hear the sound when its energy does not expand in all directions.

Roll up a sheet of construction paper, or use a cone-shaped container without ends like that shown on page 25, to make a megaphone. Talk through the megaphone to someone standing across the room. Now take the megaphone away and talk to him again. Can he hear you better with the megaphone or without it? The megaphone makes your voice seem louder because it keeps the sound waves from spreading out in all directions. Instead of the waves becoming thinner, the megaphone keeps them crowded in one direction. The energy of each sound wave is held together in a more compact unit, and more of it reaches the ears of the listener.

Beats

When two sounds of nearly the same pitch are played, the two vibrations are together some of the time, and not together at other times. Perhaps you have heard two clocks ticking when one ticks slightly faster or slower than the other. If you listen to them, you can hear one gain on the other until they are right together, then it will continue to gain until they are ticking alternately, then together, then alternately, and so on. Sound waves that are nearly of the same frequency (pitch) sometimes may spread out until the compressions of one wave come



The top lines represent waves from one note, the bottom a slightly different note. Can you find beats (where their waves strike simultaneously)? Look at the lines with your eye just above table height and you may see them.

right on top of the compressions of another wave. The combined compression the sound makes is loud at that instant. A little later the compression of one wave occurs simultaneously with the rarefaction of the other wave. The rarefaction cancels out the compression and the sound is not so loud. In this manner, sounds of slightly different frequencies make beats.

If one sound has a frequency of 250 cycles per second and another has a frequency of 251 cycles per second, the sound waves are together once each second, and they are alternating (out of phase) once each second. There seems to be an extraordinarily loud sound once each second, or one beat per second. When a piano tuner tunes the piano, he listens for beats when he strikes a string and a tuning fork at the same time. If he can hear any beats, the string and the tuning fork are not at the same pitch. When the beats disappear altogether, he knows that the string and the tuning fork are at the same pitch. Of course, he does not carry a tuning fork for each string that he tunes, but if he tunes one by means of a tuning fork, he can tell by ear and experience whether the rest are in tune.

Beats also help airplane pilots who fly conventional piston-powered aircraft to tell whether their engines are running at the same rate. When two engines are running at slightly different speeds, their vibration rates will be together (or in phase) at one instant and out of phase at another. This makes them loud and soft, loud and soft, loud and soft—a very annoying series of beats to listen to.

Outboard motors will also produce beats when two of them are running at almost, but not quite, the same speed. Listen for those few times when you can hear beats. Can you tell what makes them?

Doppler Effect

Have you ever noticed that a marching band seems annoyingly out of tune when it is passing you, but pleasingly in tune when it is not moving? This happens whenever either the listener or the instrument moves toward or away from the other. It is called the *doppler effect*, named after a German mathematician whose name was Doppler.

To understand the doppler effect, imagine a lake with waves being blown from one end toward the other by the wind—slap, slap, slap. You stand on a pier listening to the waves as they strike the pier—slap, slap, slap. Now imagine yourself stepping into a boat and rowing into the wind. The boat strikes the waves more rapidly because it is moving into them—slap, slap, slap. If you turn the boat and row with the wind, however, they strike the boat more slowly—s l a p , s l a p , s l a p . The

number of waves that strike the boat each second or minute (the frequency) varies with the direction of the boat.

Now imagine that you stand on the pier, but the lake moves with its waves instead of your moving in a boat. If the lake moved in the direction of its waves, more of them would strike the pier each second than they would if the lake moved in a direction opposite to its waves.

Sound waves act much like water waves would act. If you ride in a train when it passes the bell at a crossing, you meet each wave a little sooner than normal because you are moving toward their source. As you pass the bell and move away from it, you pass each wave a little later than normal because it takes a little time for each of them to catch up with you. The bell seems to drop in pitch as you pass it.

When a car honks its horn as it passes you on the highway, it seems to drop in pitch as it passes. When it approaches you, its waves travel faster than those from a parked car. As it recedes from you, its waves travel to you more slowly than from a parked car. If you ride in the car whose horn is honking, its horn sounds quite normal.

The next time you see someone flying a gasoline-powered model airplane, listen to the doppler effect of its motor. If you stand at one side of the circle that the plane makes, it approaches you for half the circle, and recedes from you for the other half. Durings its approach, the noise from its engine sounds a little higher than during the time it goes away from you. How many other instances of the doppler effect can you hear about you?

Loudness

Sounds of the same pitch can be loud or soft. You can strike a note on the piano softly, or you can strike it hard. It will be the same note, but its loudness will differ considerably. When you strike a string softly, it vibrates back and forth with the only frequency it knows—its own pitch. If you strike it softly, it vibrates back and forth only a little bit. If you strike it hard, it vibrates back and forth through a greater distance, but at the *same rate*. Loudness does not affect the pitch of a string or a tuning fork. It affects only the distance through which the string or the prongs of the tuning fork move. The distance through which a vibrating object moves is called its amplitude.

In stringed instruments, the amplitude of the string is the distance the string moves back and forth while the note is sounding. In a tuning fork it is the distance that the prongs of the fork move as they vibrate. In a radio speaker, the amplitude is the distance that the diaphragm of the speaker moves in

and out as it is alternately pulled and released by the magnet behind the speaker. In a piano the amplitude of the strings is controlled by the hardness with which the note is struck. In a violin, loudness is controlled by the force of the bow. In a radio or telephone, the amplitude of the diaphragm is controlled by the amount of electricity that flows through the wires leading to the magnet behind the diaphragm.

You know that if you stand close to the source of a sound, the sound is louder than if you stand at a distance. Since the sound waves spread out in all directions—up, down, back and forth, and sideways—their energy decreases rapidly with distance. At two feet, a sound is only a fourth as loud as at one foot. At four feet it is only a sixteenth as loud. Sounds decrease in loudness as the *square* of the distance from the source. That means that if you go twice as far away, the sound is not half as loud, but one fourth as loud. If you go three times as far away, it is one ninth as loud ($1/3^2$). If you go four times as far away, it is only one sixteenth as loud ($1/4^2$), and so on. How loud would it be if you went ten times as far away ($1/10^2$)? How would the loudness of a note compare to a person seated five feet away and one seated five hundred feet away? Think how sensitive your ears, and the ears of some other animals, must be to hear sounds that are many hundreds of feet away, especially when those sounds are not very loud to begin with.

On page 15 you read how sound waves are kept from spreading when they travel through a mailing tube or through a megaphone. This makes them louder than they would be if they spread out like waves that are not confined. You do not carry a megaphone with you at all times, but you can make a megaphone from your hands if you cup them around your mouth. Holding your hands at either side of your mouth while you shout helps to keep the sound going in one direction and little of its energy is lost.

If sounds are not loud enough for you to hear, you can increase their loudness by catching more of the sound waves that approach you. To do so, hold your hand around your ear as shown. Try this in a room when someone is talking and see if his voice is louder and clearer. Elderly persons often sit in a lecture with a hand cupped around an ear in order to catch more of the sound from the speaker.

A teacher in a classroom can demonstrate the effectiveness of using hands to catch more sound. As the teacher speaks in a low voice, the children can cup their hands around their ears and listen. Then they can take their hands away while the teacher continues speaking in the same tone. If the

Diane can direct her shout better by cupping her hands around her mouth.

Diane's hands also help her to hear when she cups them behind her ears.

children now put their hands in front of their ears, palms facing back-wards, they will notice that the sound is even fainter than when they do not use their hands. Holding the palms forward helps to catch sounds from in front. Holding the palms facing backwards helps to catch sounds from behind.

Animals such as dogs, cats, horses, rabbits, and deer use their ears in much the same way as we cup our hands to hear faint sounds. Watch how a dog pricks up its ears and then rotates them to catch the faintest sounds. If we had ears as big as rabbits or deer, it would help us to hear better.

Reflection of Sound

Just as a mirror reflects light, some surfaces reflect sound. The side of a building may reflect a sound back to a person, or a hill may reflect a thunderclap and make an *echo*. You can hear echoes only when the reflecting surface is distant enough for the sound that bounces back to be separate from the original sound. Sometimes an echo returns again and again as it reflects from different surfaces. The re-echoing that you can often hear in an empty room, a gymnasium, a shower room, or when thunder rolls among the clouds and hills, is called *reverberation*. Rooms that are full of people or furniture have many more surfaces to absorb sound than do empty rooms. Reverberation is seldom noticed in a full auditorium, but it is often noticed in an empty one.

Some rooms or halls are especially constructed to reflect sound.

Cornell University Professors Arthur A. Allen (aiming parabola) and Peter Paul Kellogg (operating recorder), are a world famous team. They have recorded nature's sounds all over the North American continent, and have produced 38 phonograph records of bird, insect, amphibian, and jungle sounds.

Band shells are made to reflect music to the audience in front. However, if the sound that is reflected from the shell arrives at the listener's ears much later than the sound that goes directly to them, an annoying echo will result. For this reason, band shells cannot be built larger than a certain size. The distance from band to shell to audience cannot be much greater than the distance from band to audience if echoes are to be kept to a minimum.

In football stadiums, echoes of the band can sometimes be heard

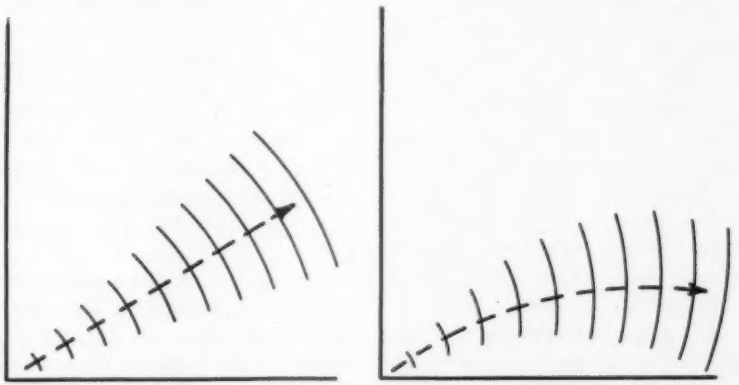
by spectators on either side. When the band plays, its music travels outward in all directions. Some of it goes directly across the field to spectators, but some of it goes back to the stadium behind the band, is reflected, and then goes to spectators across the field. Think how bad a well-drilled band can sound when this happens!

Special dish-shaped or parabolic reflectors are sometimes used in recording distant sounds such as bird songs. In a parabolic reflector, the sound waves that strike the metal or fiberglass shell are reflected to a microphone at the focus of the reflector. If the reflector is accurately made, only the sound waves coming from a single source are collected at the microphone. With a parabolic reflector, scientists can record the song of a bird several hundred feet away and at the same time exclude the songs of other birds that are not in line with the reflector.

At Cornell's Laboratory of Ornithology, parabolic reflectors on the roof of the building reflect sounds from nearby birds to microphones that are connected to amplifiers inside the observation lounge. There visitors can hear birds singing outside while they themselves enjoy the warmth and comfort of the Laboratory!

Speed of Sound

In air whose temperature is 0°C., sound waves travel at about 1090 feet per second. All sound waves, whether of low or high pitch, travel at this speed in the air. Pitch makes no difference in the speed of sound. Changing the temperature, however, changes the speed of sound.



When the temperature is lowest next to the ground (right), the sound waves bend back to earth instead of going straight out. This makes distant sounds easy to hear on a clear, winter night.

For each degree rise in temperature, sound travels two feet per second faster. At 10°C., sound would travel 1110 feet per second (1090 plus 2 × 10). At 20°C., it would travel 1130 feet per second (1090 plus 2 × 20), and so on.

On cold winter nights, the air near the ground often cools several degrees below the air above it. This affects the way sound travels on a winter night. A dog barking, for example, can be heard much farther away than normally. The sound starts out in all directions, but the sounds that slant up through the cold air into the warm air travel faster in the warm air and are thus bent back to the ground again. They cannot get out of the cold air layer very easily so the energy of the sound is kept from spreading upward. The sound is directed by temperature instead of by a megaphone.

Have you noticed how much better you can hear distant sounds at night when the sky is clear, or when you are at a lake shore? Clear skies at night help to cool the surface air. In summer, water surfaces in daytime are cooler than the air above them. Both of these help to keep sounds near the ground, rather than letting them escape through the air above.

In comparison with light, sound travels at a snail's pace. Light travels about 186,000 miles in one second. Sound travels only about one fifth of a mile in one second. Because light and sound travel at different rates, they sometimes cause problems such as the timing of a race. However, you can use them to help tell the distance of sounds such as thunder.

When a starter at a race shoots his gun, there is a puff of smoke from the end of the barrel. The light from this puff arrives at the eyes of the timers almost instantly. The sound, however, arrives a split second later. If a timer starts his watch at the *sound* of the gun, he will start the watch too late. The runners will already have left their marks. He should start it at the sight of the smoke, since that is practically the same instant that the runners standing beside the gun hear the report.

There is an interesting activity that will help show that the speed of light is greater than that of sound. If a child stands at the far end of a playground and claps his hands, the sight of his clapping will precede the sound. Unless the playground is very long, however, the difference will be only a fraction of a second. By having two children participate in hand-clapping, this difference can be magnified.

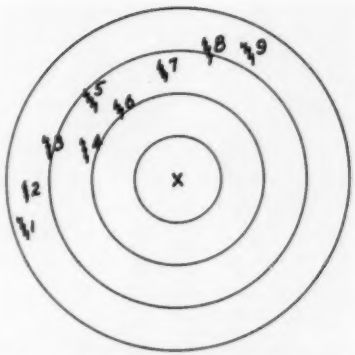
Let the two children stand back to back at one end of the school playground. One should clap his hands loudly, and the other child should clap his hands as soon as he hears his partner clap. His partner should then clap again when

he hears a clap. Each child repeats his clap as soon as he hears his partner clap. Use a stop watch to record the time needed for, say, twenty claps.

Now let the children move to opposite ends of the playground, facing each other but with their eyes closed. (Their ears must be directed towards each other in order to hear the sound at a distance.) The entire clapping exercise should be repeated, with each child clapping when he hears a clap from the far end of the field. Time the period for the twenty claps to occur, and compare this with the time it took when the children stood close together. The difference in time, divided by the number of trips the sound made back and forth between the children, will be the speed of the sound between the ends of the playground.

To compare this with light, let the same two children face each other and make movements of their hands or flash a flashlight instead of clapping. Time the twenty flashes, or the twenty hand movements. Is there any noticeable difference between the timing when they are close together, and when they are far apart? Timing these activities for twenty or more signals helps to accumulate any difference and make it more noticeable than for a single signal.

The thunder clap that follows a lightning flash is almost never heard at the same time as the flash.



Each circle represents a mile (5 seconds) from the observer. If the lightning flashes are numbered, the direction and speed of the storm can be determined.

The flash travels at the speed of light—186,000 miles a second. The thunder travels at the speed of sound—1100 or more feet per second, depending on temperature of the air.

To see how you can use sight and sound to tell the distance to a thunderstorm, draw a series of concentric circles on a paper, making the first with a one-inch radius, the next with a two-inch radius, and so on. Let the one-inch circle represent a distance of one mile from the center, the two-inch circle a distance of two miles from the center and so on. Label each of the lines according to its distance from the center. At one edge of the paper put the letter *N*. Label the other edges with *E*, *S*, and *W*, according to their directions.

On a day when a thunderstorm

is approaching, place the sheet with the *N* toward the north. Each time you see a flash of lightning, note its direction, and count the number of seconds before you hear the accompanying thunder. To count a second, repeat the words "one thousand and..." before the number as you count seconds. When you hear the thunder, divide the number of seconds by five. The approximate distance in miles to the lightning flash is the number of seconds between lightning and thunder divided by five. (Remember that it takes sound about five seconds to travel one mile.)

When you know the distance and the direction of the lightning flash, plot this on your sheet by a red *X* and wait for the next one. Keep track of the X's that you plot, numbering each one in order (1, 2, 3, and so on). Soon you can tell which way the storm is moving, and how fast it is moving.

Forced Vibration

You know now that sound is produced by an object vibrating, and that these vibrations set in motion the molecules of air around the object. When these wave motions of the molecules spread out in all directions, they press against all the objects that are in the way. Some of the objects that the air presses against are moved by the air, and others seem to resist the slight movements of the air around them. If the sound waves cause movements of another object, it exhibits *forced vibrations.*

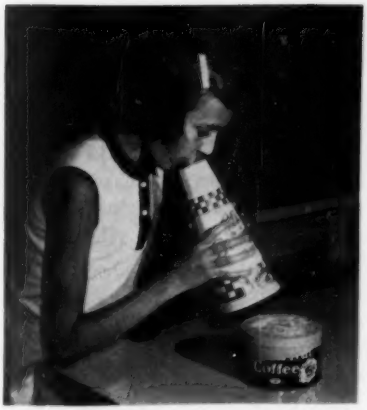
Trucks rumbling along the highway forcibly vibrate the pavement, the soil and even buildings. Often the vibration is great enough to cause cracks in the pavement and settle the soil until it is very hard. An air hammer at work breaking up a section of pavement may vibrate windows, and nearby walls. You can feel the forced vibration in a radio cabinet when sound comes from it. How many other examples can you find?

Sometimes it is annoying for an object to be forced to vibrate, but at other times it is necessary. The sounding board of a musical instrument such as a piano makes the sound much louder than it would be if there were no sounding board. You can see how this is true if you will run your finger along the teeth of a comb held in your hand, then try it again while you hold the end of the comb tightly against a window, a door panel, or the bottom of a desk drawer. If you can make a larger surface vibrate, it will send out more energy to the air that touches it and the sound will be louder.

Strike a tuning fork and hold it in front of a class. How many pupils can hear it? Now strike it again and place its base against a door panel or a desk top. Can more children hear it than before? Try the tuning fork or a comb on various surfaces around the classroom

to see which makes the best sounding board. Do hard or soft surfaces make the best sounding boards? Can you force an object to vibrate if its surface is soft?

Examine the bridge and upper surface of a stringed instrument such as a violin. When the string vibrates, it moves the bridge up and down slightly. When the bridge vibrates, it makes the upper surface of the violin vibrate, and this moves air in and out through the holes in the surface. The violin box thus becomes an efficient sounding board for the strings above it. How muted the strings would sound if there were no hollow box below them!



When the right note is sung into the megaphone, the salt on the balloon-covered coffee can will dance into patterns that show resonance.

Sympathetic Vibration or Resonance

Have you ever pushed someone on a swing, or started yourself on a swing? You know that there is a certain timing to the pushes you must make in order to make the swing move farther and farther. If you push too late, the push is ineffectual. If you push too soon, your push works against the swing instead of with the swing. By pushing just right each time, you can keep increasing the amount of the swing until it moves far and high.

The push of air molecules against some objects is like your own push against a swing. If the molecules push at just the right time, they can start an object vibrating harder and harder until you can hear its tone. *Sympathetic vibration* or *resonance* occurs when an object vibrates in tune with something else that is vibrating. If the air molecules push at a different rate, there is no sympathetic vibration.

You can find the natural frequency of an object such as a glass tumbler if you wet your finger and run it steadily around the rim of the glass. By pressing lightly then with slightly increased force, and by speeding up or slowing down your movement around the rim, you will find the right pressure and speed to make the glass vibrate. When you have reached its natural frequency, it will sing (resonate) audibly. The great tenor, Caruso, is reported to have been able to hit and maintain a note so perfectly that he could break a glass once he

found its natural frequency. The glass resonated until it shattered.

The natural frequency of a tuning fork is the frequency with which it vibrates when struck. If you get two tuning forks of the same pitch and strike one while holding the other near it, the second will begin to vibrate and will continue to do so after the first has been stopped. You can hear a similar resonance in a piano. Sit close to the strings of a piano and sing a note briefly. Stop and listen carefully. Can you hear one string continue to vibrate? If not, try again with a slightly different tone.

Sympathetic vibration may be observed even without sound. Perhaps you have noticed that at a certain speed, a window or a piece of trim on your car will vibrate audibly. When the speed of the car increases or decreases, the sound stops.

A truck moving along the street in front of a house sometimes will make a certain window in the house vibrate. Other vehicles may not do it at all. When the refrigerator motor turns on, you may hear the lid on a dish vibrate inside the refrigerator, if the lid has a natural frequency that is the same as that of the motor.

The Tacoma Narrows bridge in the State of Washington was once dubbed "Galloping Gertie" because of the way it swayed when winds of a certain velocity blew against it. On November 7, 1940, the wind blew against it steadily at just about the right (wrong?) speed until resonance began in the bridge. It swayed more and more until it finally crashed into the water below, carrying an automobile with it.

At Cornell, as at many other universities, exuberant spectators sometimes pull down the goalposts after a victorious football game. The goalposts at many fields are made of wooden posts, about four inches square. These posts, strong as they are, are no match for a group of husky fellows who find the natural frequency of the posts and begin to sway them back and forth. If their pulls and pushes are timed correctly, they can snap off the posts after a few seconds of resonance.

Before armies were mechanized, it was customary to have the marching soldiers break step as they crossed bridges, so their rhythm would not coincide with the natural frequency of the bridge and cause it to collapse. In World War II, soldiers training at Atlantic City, New Jersey, marched up and down the famous boardwalk. Occasionally, a platoon of marching men would find a marching frequency that would cause the boardwalk and its tall streetlights to resonate. If they maintained this cadence, they sometimes shook loose the glass globes in the lights and sent them crashing down to the walk below. Finally, an order was issued prohibiting marching in cadence on the boardwalk!

Although resonance can sometimes be a problem, it is being investigated by scientists for its benefits. Many objects that have a natural frequency within the range of sound waves can be vibrated by directing the proper sound waves in their direction. One experimenter found that fog could be dispelled by means of sound. Because fog is a mixture of tiny water droplets of varying sizes, it is possible to make the smallest ones vibrate while the larger ones do not. This causes the small droplets to collide with the larger ones and make them still larger until they begin to fall. This experiment in fog dispelling was conducted in England during World War II, but proved to be more interesting than practical because of the tremendous amount of sound needed to clear an airport of fog.

A more recent experimental use of sound waves involves the resonance of microscopic bodies such as bacteria. It is possible to literally shake to pieces small cells through the use of certain sound waves—often at pitches too high to be heard by humans. Perhaps someday a sound will be beamed at an infection in order to kill the germs that caused it, or food may be preserved from spoiling by treating it with sound.

Sound may help or it may hinder as other things vibrate in resonance with it. As you listen to various sounds around you, look for examples of resonance. Listen for peculiar vibrations that occur whenever a certain machine starts up, or for a flower vase that rattles whenever one low note is played on the radio, or the window that rattles when the wind is from a certain direction, or the auto brake that squeals when pressure is applied. How many clues can you find to things that vibrate in tune with something else.

Sounds in Other Media

You read on page 21 that sound travels 1090 feet per second in air at 0°C., and a little faster than that when the air is warmer. Sound travels at higher speeds in materials that are denser than air. In materials that are less dense than air, sound travels even slower than it does in air. The speed of sound in some solids, liquids, and gases is given below:

	Number of feet per second
Iron	16,000
Granite	20,000
Glass	16,000
Pine	11,000
Cork	1,650
Lead	4,000
Water	4,700
Air	1,090
Hydrogen	4,170
Carbon dioxide	846

From this table you can see that in hydrogen, lightest of all gases, sound travels nearly as fast as it

does in water. Even though lead is more than a hundred thousand times as heavy as hydrogen, sound travels faster in the hydrogen than in lead. It is only generally true that sound travels faster in more dense materials; there are many exceptions to the rule.

Even the bones of your head transmit sound readily. A simple experiment will help to show this. Strike a tuning fork several feet away from a person and ask him to indicate when he no longer hears the tone. When he can no longer hear it, ask him to bite on the end of a long stick while you hold the base of the tuning fork against the opposite end. He may be surprised to hear the tuning fork now.

Some people who have suffered some loss of hearing because of damage or disorders of their hearing apparatus can still perceive vibration through the bones of their skulls. Some hearing aids amplify vibrations and send them through these bones to the inner ear.

Not only do some solids conduct sound faster than other materials, but they conduct it better. You can hear faint sounds tapped out on a steam pipe several rooms away in a building, but you cannot hear the sounds coming through the air. Try to tap out a message to someone in another room, first tapping on a piece of wood held in your hand, and then tapping on a water pipe or a steam pipe. Which of the two sounds carries better?

Shock Waves in the Earth

When an earthquake occurs, waves similar to sound waves travel out in all directions. Because the vibration rate of these waves may be too slow to hear, we do not often get an audible sound. The rocks of the earth, however, transmit these waves through the crust and through the interior to deeper, denser layers of rock. The waves that travel through the crust move at a different speed from those that reflect from the deeper, denser layers. By means of the time interval between the reflected shock wave and the direct shock wave, scientists can tell how far away the earthquake occurred. If three stations record the shocks of an earthquake, it is possible to tell where its epicenter (the point above the earthquake at the earth's surface) is located. Circles whose radii represent the distance from each seismograph (an instrument that records the earth's vibrations) are drawn on a map. Where the circles intersect is the epicenter of the earthquake.

Shock waves similar to earthquake waves are also caused by underground atomic explosions. These, too, can be recorded by sensitive seismographs, and their distances determined by the difference in time required for the wave to travel through the lighter rocks of the earth's crust, and the heavier rocks farther down. Part of the

difficulty in arriving at a satisfactory plan for monitoring atomic tests in the United States and Russia, however, is that the shock waves from these underground atomic tests are not different from those of mild earthquakes. This makes it impossible to tell earthquakes from illegal underground atomic tests. Perhaps newer ways to interpret shock waves in the earth's crust will be developed even as you read about sound in this Leaflet.

Supersonic Sounds

Human ears are sensitive only to sounds with frequencies between about 20 and 15,000 c.p.s. (cycles per second). Many sounds, however, have vibration rates far above 15,000 c.p.s. Bats, for example, are known to communicate with sounds ranging to 50,000 c.p.s. With these sounds, bats can locate and avoid obstacles such as wires and branches. At the same time they can use their sounds to locate prey such as moths and night-flying beetles.

A sound that has a frequency of 50,000 c.p.s. and travels 1150 feet per second has waves that are only about one-quarter inch apart. Waves this close together can sense a large beetle or a leaf. If we could use our ears as bats do, sounds that we hear, with our limit of about 15,000 c.p.s., could sense only objects as large as a golf ball. Our speaking voice vibrates at less than 1000 c.p.s., and this frequency could

A supersonic navigator—the brown bat.

sense only objects no smaller than a basketball! Do you see why bats who fly and feed in the twilight must have some means of locating their prey other than by sight?

Recent experiments with fish indicate that they, too, communicate by sounds that we cannot hear. Sharks may be attracted to their prey with the help of sounds that travel through the water to special hearing devices along their sides.

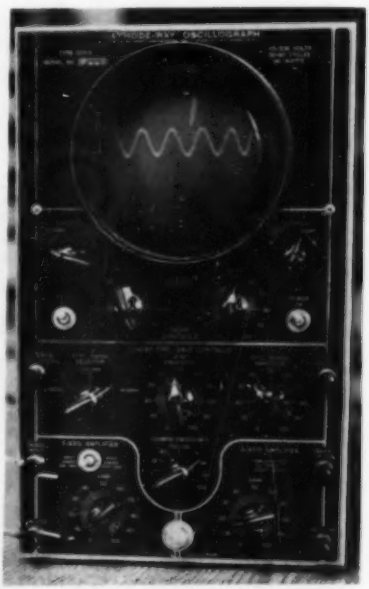
Some supersonic sounds have become a medical problem on many jet airfields. Some of the high speed parts of jet engines seem to produce sounds that are inaudible, but which may cause damage to delicate parts of the human nervous system. Scientists are now studying these sounds and trying to eliminate those that seem to be damaging. How frustrating and yet how challenging it must be to study a sound that one cannot hear!

When you hear an audible sound, think of the tremendous number of other sounds that may be present, but which you cannot hear. Perhaps the air is full of energy from a thousand sounds, only a few of which fall within our restricted range of hearing. Even the symphonies that we listen to may be producing many beautiful notes that are just beyond our aural grasp, and certainly many of the smaller animals are communicating in a way that we have only begun to appreciate.

Machines That Hear

Scientists who study vibrations of various kinds are limited as you and I are, in direct response to many vibrations. They can hear many sounds whose frequencies range from 16 v.p.s. to 15,000 v.p.s., but beyond those limits they cannot hear without the help of some special electronic equipment. Often an instrument called an *oscilloscope* is used to help interpret supersonic vibrations.

An oscilloscope contains a cathode ray tube that shoots out a beam



A single note shows on the oscilloscope screen as a sine wave. The higher the pitch, the closer together are the waves.

of electrons against a fluorescent screen very much like a television screen. The beam of electrons can be made to move back and forth as well as up and down when certain vibrations strike its electrical system. When sounds strike a microphone and become electrical pulsations, the beam shows them as wavy lines on the screen.

You can see what kinds of lines an oscilloscope produces if you move a pencil back and forth on a sheet of paper while someone pulls the sheet steadily in a direction at right angles to the direction of your pencil. If your pencil moves back and forth rapidly from right to left and left to right while someone pulls the paper away from you, the line will resemble that on page 30. When a person speaks into an oscilloscope, the pattern of the sound becomes quite complicated because the frequencies change rapidly and are not constant like a tuning fork. With the aid of an oscilloscope, scientists have succeeded in analyzing bird songs, insect songs, bat communication, and even fish "whisperings."

As you listen to all the sounds about you, remember that you are hearing but a fraction of the vibrations that are really there. Of those that you do hear, listen for the interesting things you have learned about sound. Resonance, doppler effect, beats, and all the other qualities of sound will enhance immeasurably your listening.

Some Helpful References

BAER, MARIAN, SOUND, *Holiday House, Inc., New York, 1952. 125 pages.* Nearly fifty observations and experiments with vibrating objects are arranged from simple to complex. Common household materials and utensils are used to make sound apparatus. Primary, intermediate.

BARROW, GEORGE, YOUR WORLD IN MOTION, *Harcourt, Brace and Company, New York, 1956, 175 pages.* Chapter 11 describes the causes and the effects of sound, particularly in music. It is followed by a chapter on the telephone and how it works. Intermediate, upper.

GLEMSER, BERNARD, ALL ABOUT THE HUMAN BODY, *Random House, New York, 1958. 132 pages.* Contains four pages on the ears and how they work. Illustrated with clear, simple diagrams. Intermediate, upper.

KETTELKAMP, LARRY, DRUMS, RATTLES, and BELLS, *William Morrow and Company, Inc., New York, 1960.* The story of percussion instruments, from the earliest ones to modern orchestral instruments and church chimes. Includes descriptions of simple instruments that children can make at school and home. Primary, intermediate.

KETTELKAMP, LARRY, THE MAGIC OF SOUND, *William Morrow and Company, Inc., New York, 1956. 64 pages.* String, paper cups, a soda straw, and a drinking glass are used in simple experiments to illustrate the basic principles of sound. Musical sounds, and the production of sounds for radio and television are described. Intermediate.

KNIGHT, DAVID, THE FIRST BOOK OF SOUND, *Franklin Watts, Inc., New York, 1960. 90 pages.* How sound is caused, and how it travels are carefully explained, as are its characteristics, and some of its modern applications in ultrasonics. The text finishes with a brief set of simple experiments in sound. Intermediate, upper.

PINE, TILLIE, and LEVINE, JOSEPH, SOUNDS ALL AROUND, *Whittlesey House, New York, 1958. 47 pages.* In cartoon and simple text, the common sounds around us are described for little readers. How sounds travel (in air, pipes and strings), and how to change sounds are also described. Primary, intermediate.

RIPPER, CHARLES, BATS, *William Morrow and Company, New York, 1954. 64 pages.* Along with its life-history of bats, there is a description of the use of high-pitched sounds by bats for food getting and navigating around obstacles. Intermediate, upper.